

# Cosmic Ray Anisotropy Studies at EeV Energies



The Pierre Auger Collaboration  
Presented by  
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# Overview

- Motivation
  - Astronomy?
  - Connection between EeV energies and anisotropy (Magnetic Fields)
- The acceptance of the Auger detector
- Small Scale Anisotropy
- News from the galactic center

# The Auger Observations

- Surface detector
- Fluorescence detector
- Energy
  - Above 0.1 EeV ( $E = 10^{18}$ )
- Position
  - (time,  $\theta$ ,  $\phi$ )  $\longrightarrow$  ( $l$ ,  $b$ )
- Composition
  - Atmospheric depth of shower max

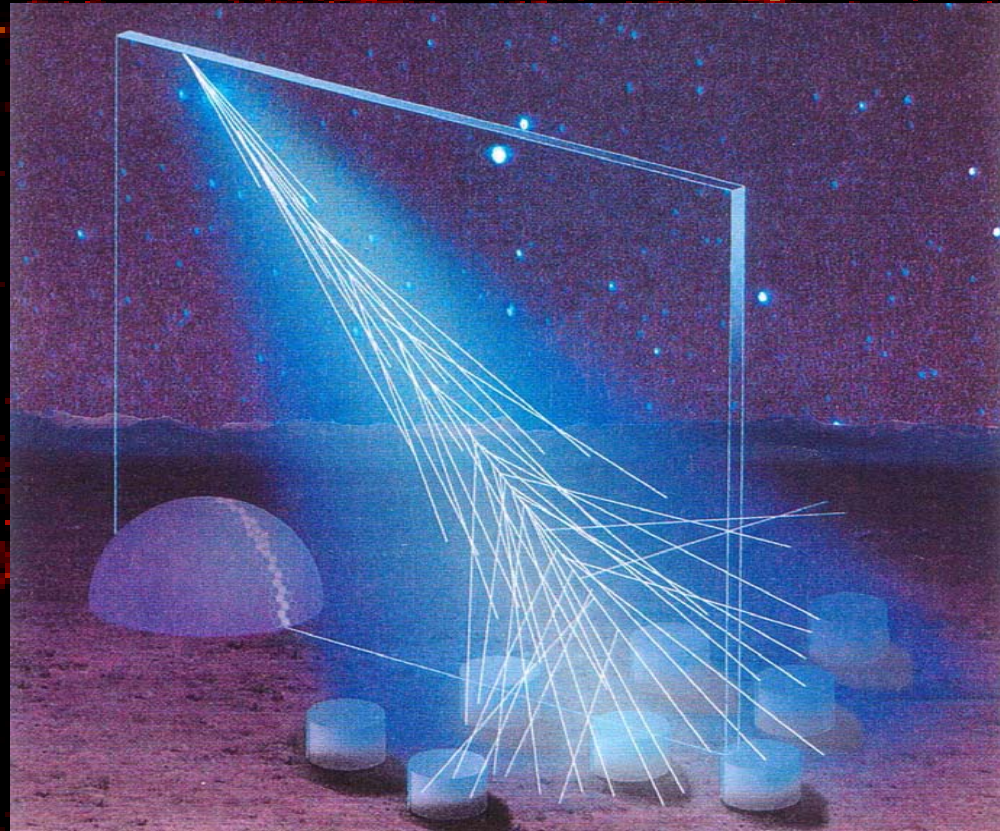
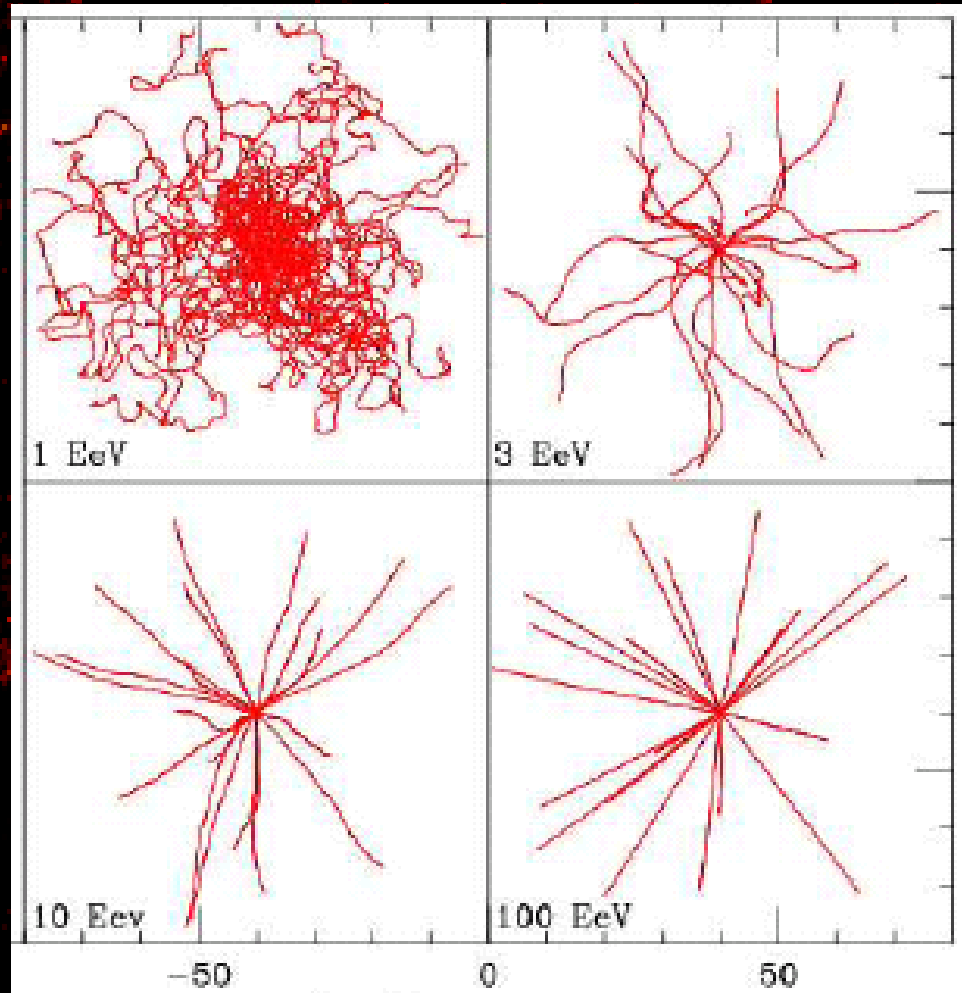


Figure courtesy of Paul Mantsch

# Astronomy

- Charged particle primaries are significantly deflected by magnetic fields
- Right: proton primaries propagating through random magnetic fields
  - B direction random
  - Cell size = 1 Mpc
  - $B = 10^{-9}$  gauss



EeV =  $10^{18}$  eV

Diagram from Cronin (TAUP 2004),

# Astronomy

- Galactic  $B \approx 10^{-6}$  gauss
  - $E \lesssim 1$  EeV isotropized, trapped in galaxies
- Intergalactic  $B$  less understood
  - Galactic-extragalactic transition in energy spectrum may occur near 5 EeV
- Assuming inter-cluster  $B \approx 10^{-9}$  gauss,
  - $E \gtrsim 40$  EeV deflected by  $4^\circ$ - $6^\circ$  (at 40Mpc)
- Thus UHECR are more likely to
  - be of extragalactic origin
  - exhibit meaningful local excesses.



# Events Map

- 29,073 Auger events from 1/04 to 5/04 with energies 1-5 EeV
- Data is smoothed, greatest angular error is about  $2.2^\circ$

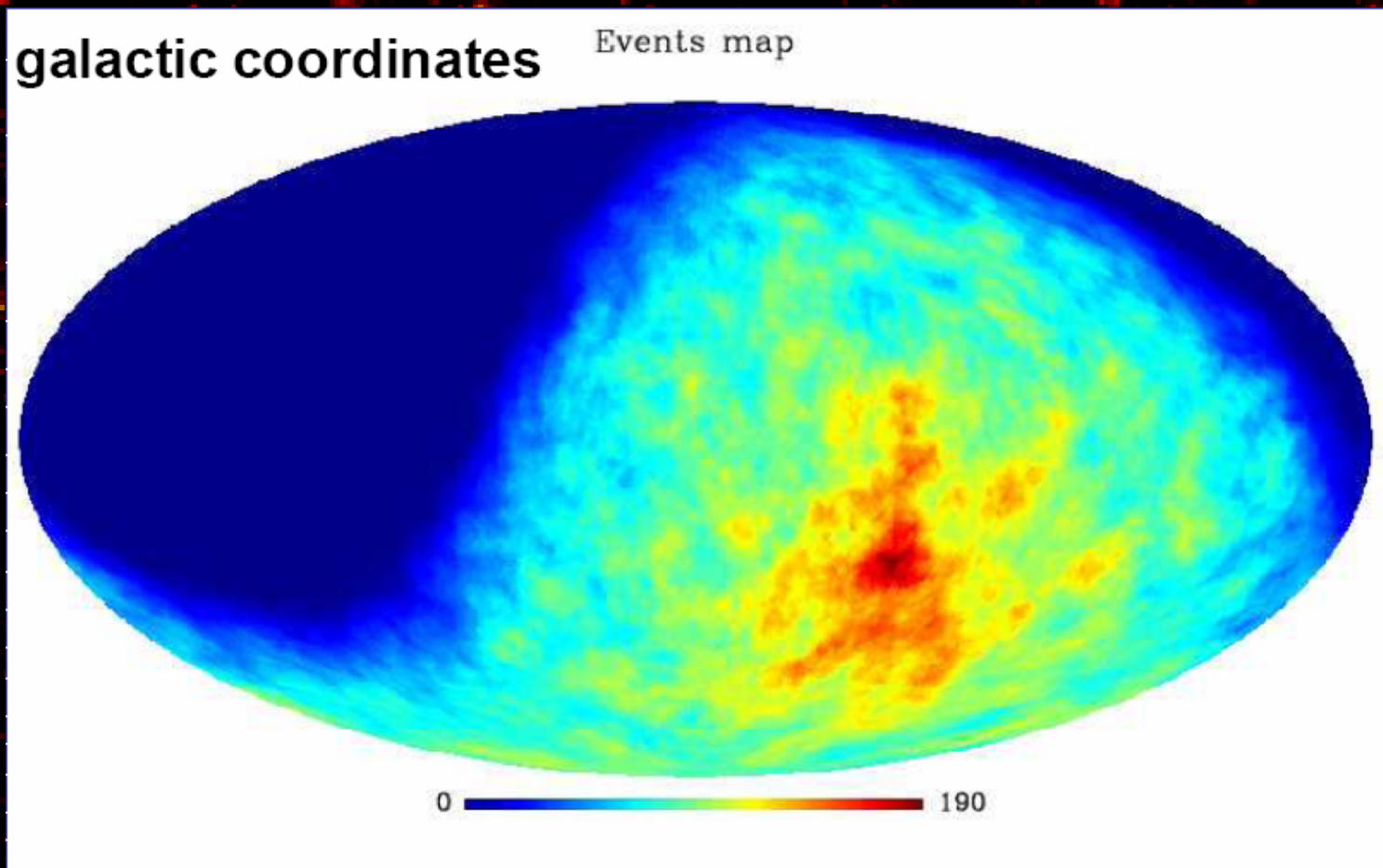


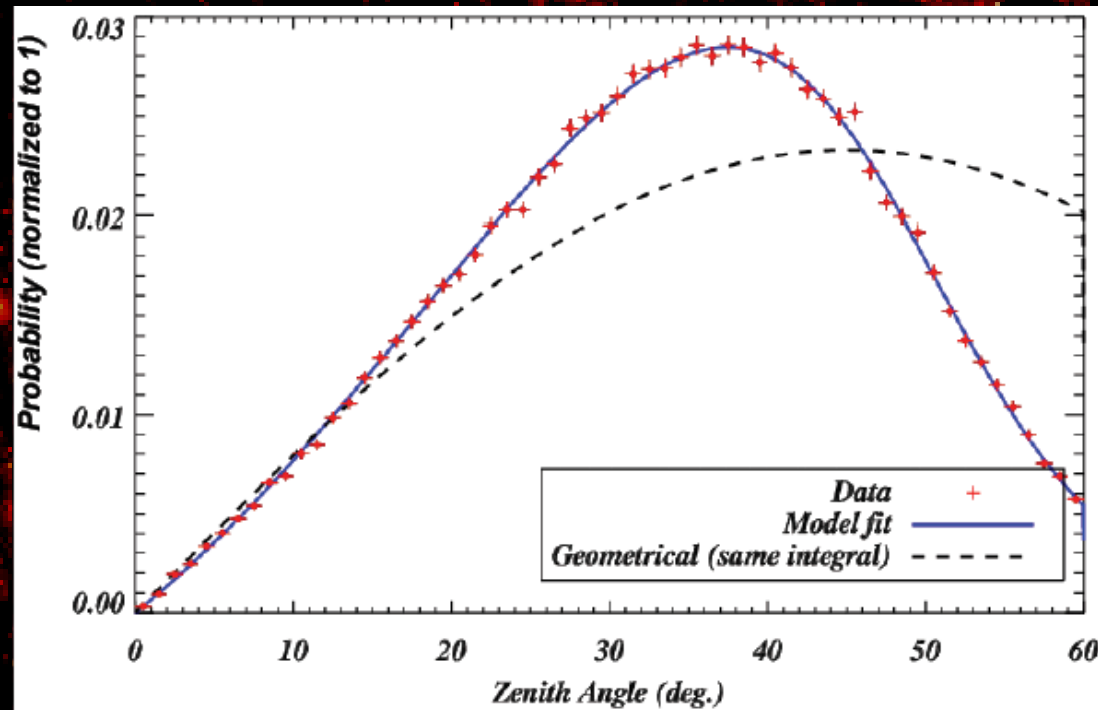
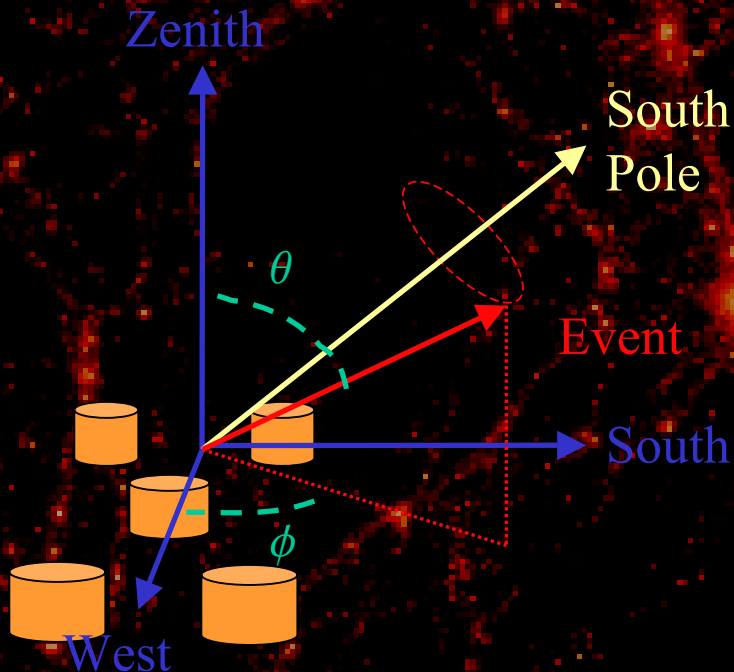
Figure courtesy of Benoît Revenu (29th ICRC 2005, Pune India)

# The need for an Exposure Map

- Relative # of events expected from an isotropic sky, a.k.a Coverage Map
- Clustering signal is measured with respect to Auger exposure from isotropic sky
- Exposure map can be extracted from data
  - Best event reconstructions for local altitude  $< 60^\circ$
  - Fixed detector, moving Earth  $\Rightarrow$  pan over Ra and Dec
- Two main approaches
  - Shuffling method naturally accounts for changing local conditions, e.g. weather, detector area
  - Analytic fit to event density data

# The Analytic Fit

- Uniform in azimuth ( $\phi$ )
- Uniform in sidereal time (nearly)
- Parameterized zenith angle  $\theta$  fit
  - Geometric:  $\sin(\theta)\cos(\theta)$
  - Energy dependence:  $\text{Poly}(\theta)$



Figures courtesy J.-Ch. Hamilton



# Exposure Map

- Map  $(\theta(t), \phi(t)) \rightarrow (l, b)$
- Overall form most important for SSA
- Note the over exposure at the ecliptic south pole

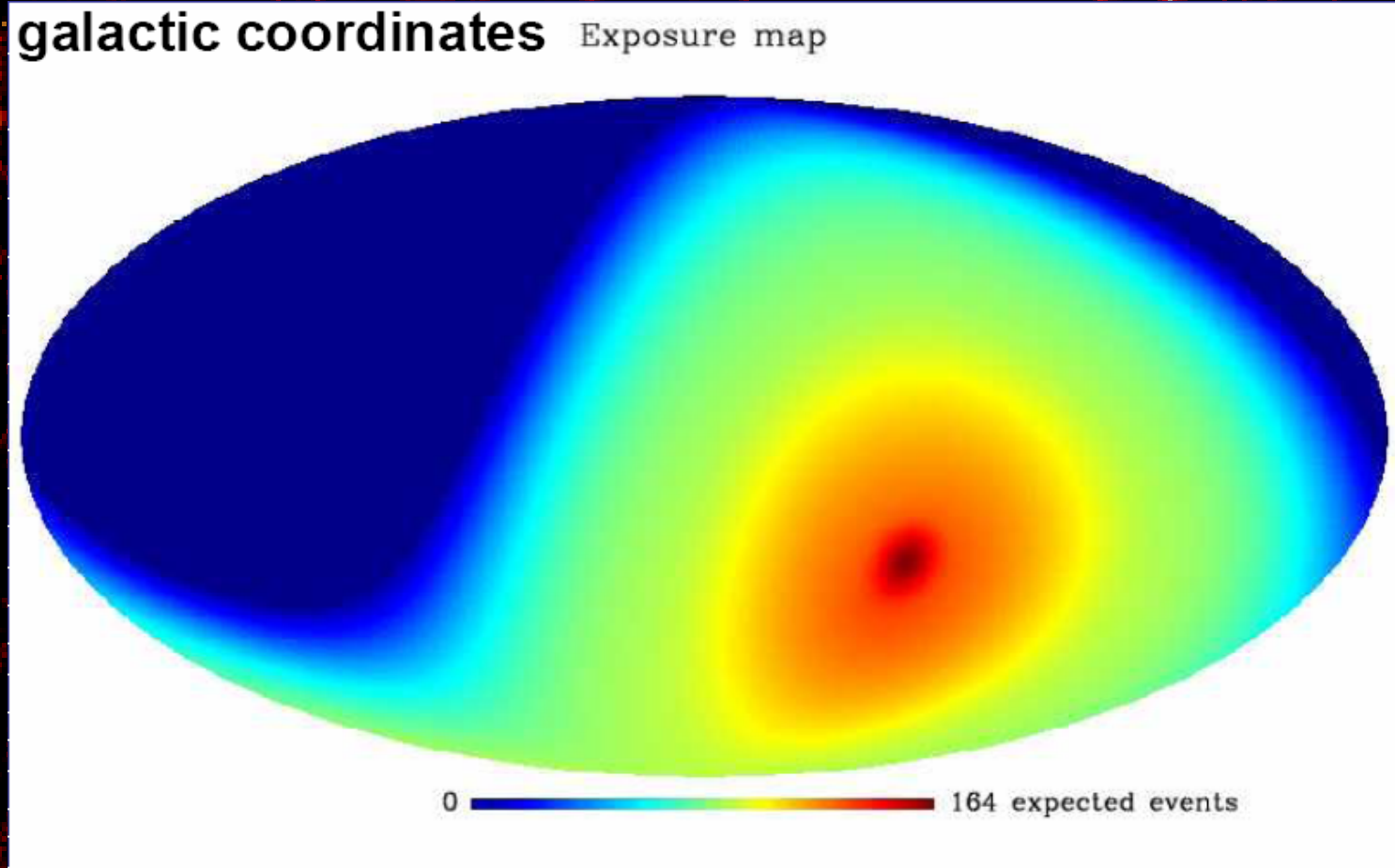
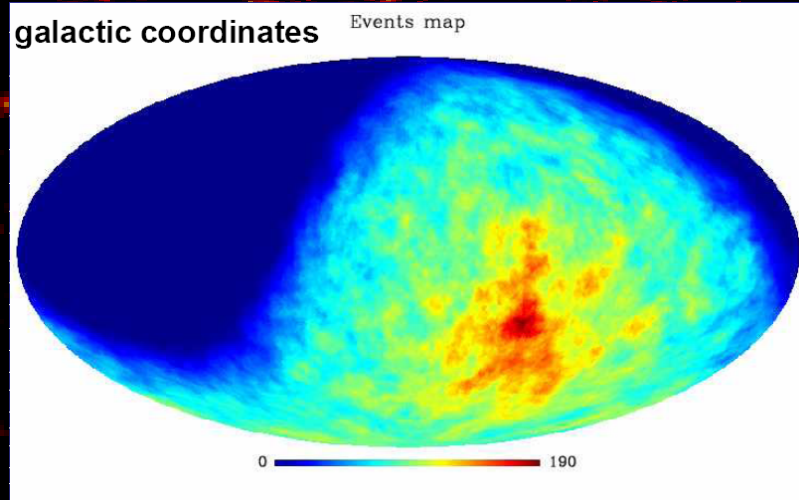
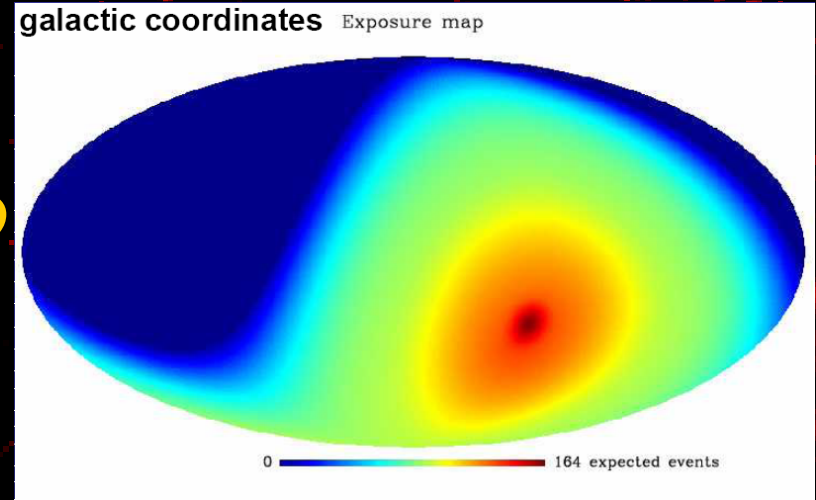


Figure courtesy of Benoît Revenu (29th ICRC 2005, Pune India)

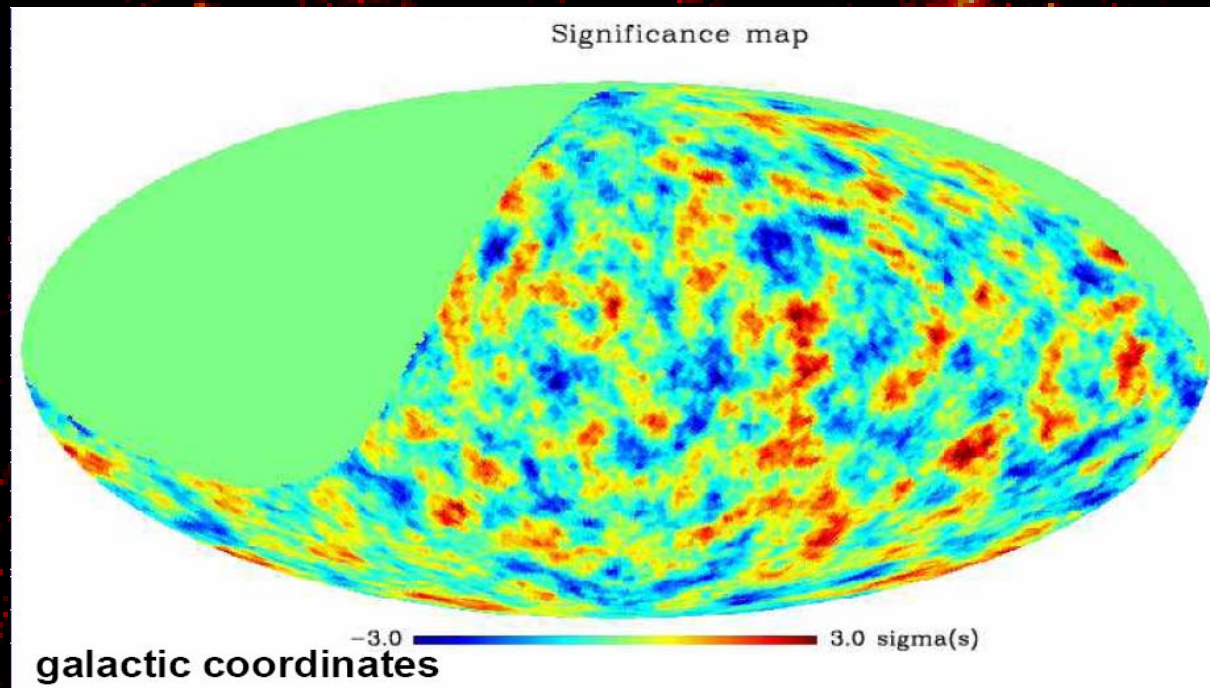
# Blind Search



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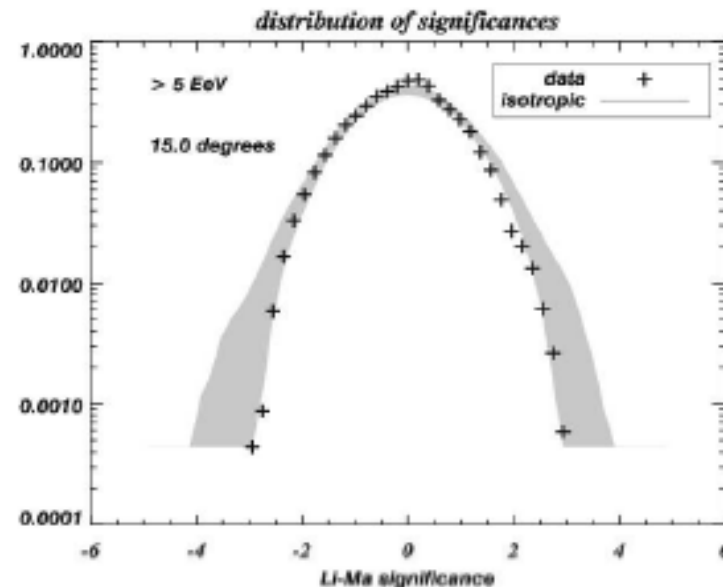
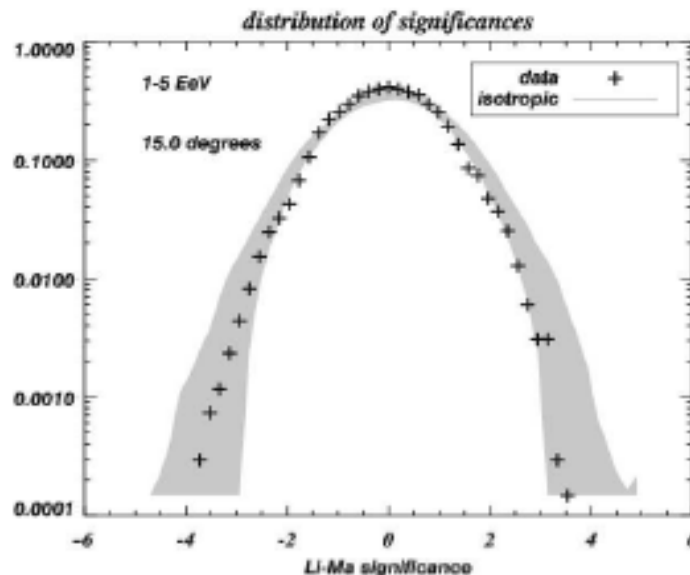
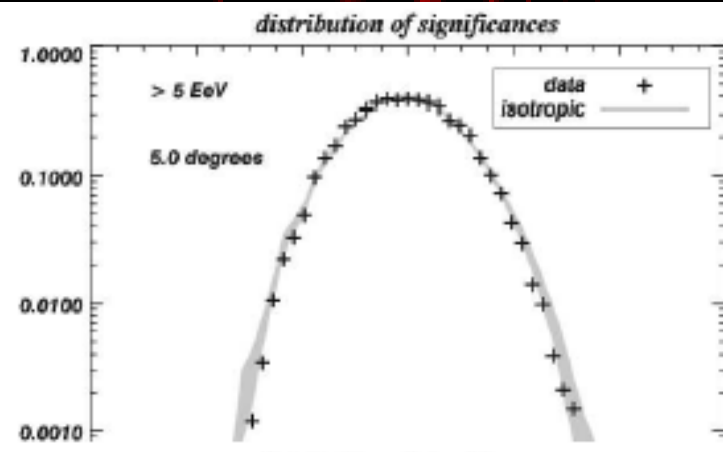
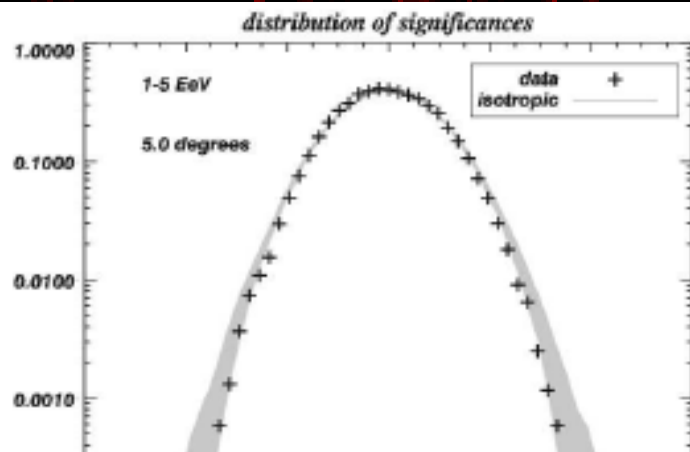
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Figures courtesy of Benoît Revenu (29th ICRC 2005, Pune India)

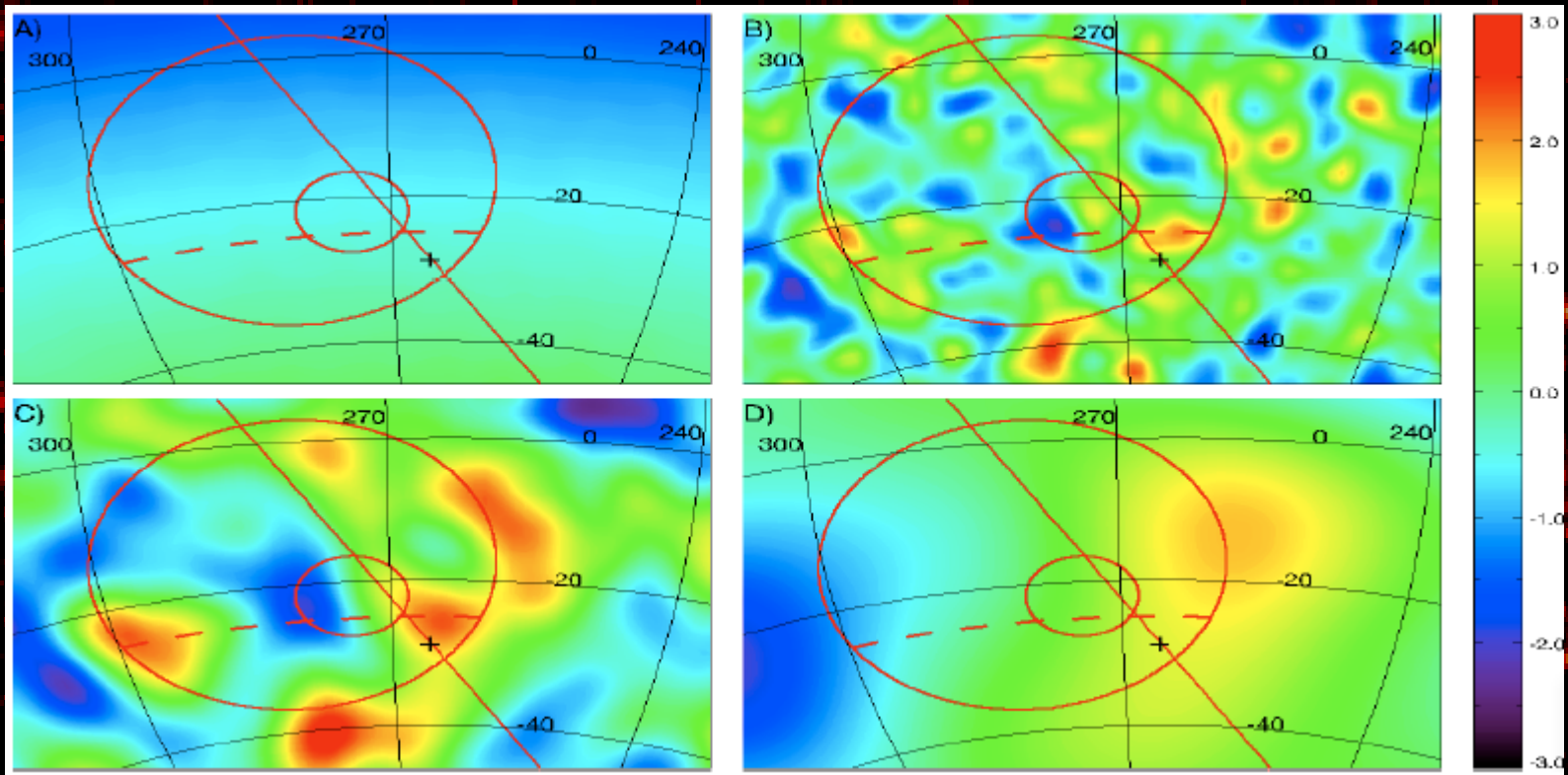
# Distribution of Significances

- Distribution of significances must be compared with that of a large number of Monte Carlo simulations
- Shaded areas correspond to  $1\sigma$  dispersion of the isotropic simulations



# Galactic Center

- Lots of action near the galactic center, including a very large black hole
- AGASA
  - 1.0-2.5 EeV reported excess would translate into  $\approx 5.2\sigma$  excess in the Auger data
  - 3 times more statistics and no confirmation
- SUGAR
  - Also reported significant excess near GC
  - 10 times more statistics and no confirmation



GC (cross), galactic plane (solid line), regions of excess of AGASA and SUGAR (circles), AGASA f.o.v. limit (dashed line)

- A) coverage map, same color scale as the significance maps, but in a range [0-1.0]
- B) significance map in the range [0.8-3.2] EeV, smoothed using the individual pointing resolution of the events and a  $1.5^\circ$  filter (Auger-like excess)
- C) same, smoothed at  $3.7^\circ$  (SUGAR-like excess)
- D) in the range [1.0-2.5] EeV, smoothed at  $13.3^\circ$  (AGASA-like excess)

Figures courtesy of A. Letessier-Selvon (29th ICRC 2005, Pune India)



# Conclusion

- No significant excesses observed in blind sky search
- No confirmation of AGASA claim near GC
- “Astronomy” may be possible with events with energy greater than 10 EeV
  - Look for maximum likelihood search in this range.

